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FROM  $(n, n')$  and  $(n, 2n)$  REACTIONS

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## ABSTRACT

Energy spectra of neutrons from  $(n,n')$  and  $(n,2n)$  reactions induced by 14 MeV neutrons have been calculated in terms of the original Weisskopf model for a number of target nuclei. The results of the calculations which avoid the usual approximations show very good agreement with the experimental data.

## РЕЗЮМЕ

На основе оригинальной модели Вейскопфа было определено распределение по энергии нейтронов, возникающих в реакциях  $(n, n')$  и  $(n, 2n)$ , вызванных нейтронами с энергией 14 Мэв. В случае большого числа ядер мишени расчетные и измеренные значения хорошо согласовывались.

## KIVONAT

Az eredeti Weisskopf modell keretében kiszámítottuk a 14 MeV-s neutronokkal előidézett  $(n,n')$  és  $(n,2n)$  reakcióban kilépő neutronok energiaeioszlását. A számított és mért értékek nagyszámu targetmag esetében nagyon jó egyezést mutatnak.



## 1. INTRODUCTION

The study of inelastic neutron scattering (INS) and  $(n, 2n)$  reactions is especially useful for the investigation of the internal structure of nuclei at excitation energies of several tens of MeV. A considerable number of neutron spectra from  $(n, n')$  and  $(n, 2n)$  reactions measured at 14 MeV bombarding neutron energy has been already reported and analyzed by fitting with simplified evaporation formulas derived in terms of the compound nucleus (CN) theory. It will be shown that more precise CN model calculations can prove more definitely the validity of the CN model or that they can give more information about the effect of the direct reaction mechanism.

## 2. THEORY

As a rule, in a considerable part of the possible energy interval neutrons from both  $(n, n')$  and  $(n, 2n)$  reactions contribute to the energy spectra of the neutrons emitted at 14 MeV bombarding neutron energy. Assuming that the excitation energy of the compound nucleus with  $N$  neutrons and  $Z$  protons ( $A = N + Z$ ) is so high that the statistical theory applies to both the compound and the residual nuclei, the energy spectra of the emitted neutrons can be reasonably well described in terms of the original Weisskopf formulation [1].

If, the residual nuclei after the first neutron emission have enough energy for the emission of further neutrons, the contribution from the latter enters as an additional term into the differential cross section in the form

$$\frac{d\sigma}{dE} = N(E) \sim \varphi_1(E) + C_2 \varphi_2(E) \quad /1/$$

where  $\varphi_1(E)$  and  $\varphi_2(E)$  are the contributions from the first and that from the second neutron emission, respectively.  $\varphi_1(E)$  and  $\varphi_2(E)$  are given by



$$\varphi_1(E) = Q_1 E \sigma_A(E) \frac{\omega_{A-1}(E^* - B_A - E)}{\omega_A(E^*)} \quad /2/$$

$$\varphi_2(E) = Q_2 \int_0^{K_2-E} \varphi_1(E') E \sigma_{A-1}(E) \frac{\omega_{A-2}(E^* - B_{A-1} - B_{A-2} - E' - E)}{\omega_{A-1}(E^* - B_{A-1} - E')} dE' \quad /3/$$

where the constant  $Q_1$  is chosen such that we have

$$\int_0^\infty \varphi_1(E) dE = 1 ,$$

while the constant  $Q_2$  leads to

$$\int_0^\infty \varphi_2(E) dE = 1 .$$

$\sigma_i(A)$  and  $B_i$  are the capture cross sections for neutrons of energy  $E$  and the binding energies, respectively in nuclei with  $i = A, A-1, A-2$ .  $E^*$  is the initial excitation energy of the compound nucleus with mass number  $A$  and  $K_2 = E^* - B_A - B_{A-1}$  stands for the maximum energy of the second neutron.

The relative strength  $C_2$  of the second term is determined by Weisskopf's hypothesis that neutrons are always emitted if it is energetically allowed. This can be expressed by the condition that

$$\int_0^{K_2} \varphi_1(E) dE = C_2 \int_0^{K_2} \varphi_2(E) dE = C_2 .$$

The spectra  $\varphi_1(E)$  and  $\varphi_2(E)$  are usually approximated by simple evaporation spectra with parameters  $T_1$  and  $T_2$ , respectively. The differential cross section is then given as

$$N(E) = \sigma_{n,2n} \left\{ \frac{1}{1+\eta} \frac{E}{T_1^2} \exp\left(-\frac{E}{T_1}\right) + \frac{\eta}{1+\eta} \frac{E}{T_2^2} \exp\left(-\frac{E}{T_2}\right) \right\} \quad /4/$$

where  $\eta = \frac{\sigma_{n,2n}}{\sigma_{n,n'}}$  with  $\sigma_{n,n'}$  and  $\sigma_{n,2n}$  being the total cross sections for  $(n,n')$  and  $(n,2n)$  reactions.

This approximation is theoretically difficult to justify and seems to have been adopted only because an approximation of this type works well for the simple  $(n,n')$  reactions.



An alternative approach is the Le Couteur and Lang type [2] cascade calculation, applicable to cases when the initial excitation energy is high enough for several neutrons to be emitted in succession. The differential reaction cross section is then approximated by

$$N(E) \sim E^{5/11} \sigma_A(E) \exp\left(-\frac{E}{T_{\text{eff}}}\right) \quad /5/$$

where the parameter  $T_{\text{eff}}$  is related to the nuclear temperature  $T_1$  governing the emission of the first neutron as

$$T_{\text{eff}} = \frac{11}{12} T_1$$

This approximation to  $(n, 2n)$  reactions is questionable because of the relatively low excitation energies available for the successive neutron emission in our case. This fact is apparent from a number of energy spectra measured by Anufrienko et al. [3] and Salnikov et al. [4] at 14 MeV bombarding neutron energy. These authors tried to make eye-guide fits to the emitted neutron energy spectra some of which resembled the form of eq. /4/ while others were more similar to the form of eq. /5/.

### 3. CALCULATIONS

The cross section calculations were made for a two-step neutron cascade emissions using the formula /1/ derived from the CN theory without having recourse to such rough approximations as involved in expression [4]. We worked also without the assumption of such high excitation energy as needed for a high emission probability of several neutrons. All the approximations used in our calculations are theoretically established and well defined.

It can be seen that the neutron capture cross section in eq. /1/ cover a rather wide energy interval comprising quite low energies, too. Since in this case it seems inadmissible to assume the neutron capture cross section to be constant, we used the empirical formula of Dostrovsky et al. [5] which approximates the energy and mass dependence of the neutron capture cross sections fairly well for nuclei with mass numbers similar those involved in our calculations, and has the form



$$\sigma_A(E) \sim \alpha + \beta/E$$

where  $\alpha = 2.2 + 0.7 A^{2/3}$  and  $\beta = 2.12 A^{-2/3} - 0.05$

The level densities were obtained by the method of Gilbert and Cameron [6] who used a "constant nuclear temperature" approach at low excitation energies and the regular Fermi gas formula containing pairing and shell corrections at higher excitation energies at which the density of the energy levels at energy  $E$  is given as

$$\omega_1(E) = \text{const.} \exp(2\sqrt{aU}) / (a^{1/2} U^{3/2} A^{1/3})$$

where  $U = E - P(Z) - P(N)$ , and  $P(Z)$  and  $P(N)$  are the pairing energies. Below a given energy  $E_x = 2.5 + 150/A + P(Z) + P(N)$  (MeV)

$$\omega_2(E) = \frac{1}{T} \exp[(E - E_0)/T]$$

where  $E_0$  and  $T$  are determined by equalizing the two level densities  $\omega$  and their derivatives at  $E = E_x$ . The parameter  $a$  in the formula for  $\omega_1(E)$  is given as

$$a = (0.00917S + C)A$$

where  $S = S(Z) + S(N)$  are the shell corrections and the value of  $C$  is 0.142 for undeformed 0.120 for deformed nuclei. The numerical values of  $S$  and  $P$  were taken from ref. [3].

#### 4. RESULTS AND DISCUSSION

The experimental data [3,4] are compared with the results of our calculations in figs. 1-3. For most of the nuclei under consideration the predictions are in surprisingly good agreement with the experimental values, if one considers that statistical description without free parameters and a more rigorous treatment has been used than in the earlier approaches. Even for the nuclei Mg, S, Ca where the calculations for a target of natural isotopic abundance failed to reproduce the experimental  $(n,2n)$  contribution, show very good agreement if we calculate only with contributions from the specific isotopic subject to



(n,2n) reaction  $^{25,26}\text{Mg}$ ,  $^{34}\text{S}$ ,  $^{44}\text{Ca}$ .

The deviations at higher energies can be attributed to contributions from direct reactions, uncertainties of level densities and neutron capture cross sections.

The numerical results of our calculation for the sum of contributions from (n,n') and (n,2n) reactions are included in Tables 1-6. Tables 5-6 contain the numerical spectra for  $^{25}\text{Mg}$ ,  $^{34}\text{S}$  and  $^{44}\text{Ca}$  target nuclei. Also examples with somewhat changed level density parameters as tests for the sensitivity of the results for the income parameters are included.

The shapes of the spectra of neutrons from (n,n') and (n,2n) reactions, respectively, are determined by the values of neutron binding and pairing energies. The relative positions of these two spectra and that of spectra from different isotopes cause in some cases remarkable deviations from a single smooth deepless composed spectrum.

The advantage of the method is that it avoids the use of different evaporation formulas with one or two "nuclear temperatures", the physical interpretation of which is always ambiguous.

As compared with the detailed Hauser-Feshbach method [7] the computational process is more simple and therefore it can be extended with a reasonable time consumption to energy spectra of cascades with several terms and to a large number of nuclei as required e.g. for fission neutron spectrum calculations [8].



Table 1

$E_n$ MeV	N(E)			
	Na	K	Ti	In
0.2	0.2097	0.2464	0.2653	0.3823
0.4	0.2544	0.2631	0.3470	0.4977
0.6	0.2642	0.2306	0.3821	0.5292
0.8	0.2504	0.1882	0.3876	0.5129
1.0	0.2230	0.1817	0.3770	0.4717
1.2	0.1909	0.1916	0.3518	0.4198
1.4	0.1620	0.1973	0.3182	0.3653
1.6	0.1459	0.1994	0.2809	0.3127
1.8	0.1480	0.1986	0.2438	0.2645
2.0	0.1485	0.1958	0.2101	0.2215
2.2	0.1476	0.1910	0.1822	0.1841
2.4	0.1456	0.1849	0.1630	0.1520
2.6	0.1427	0.1777	0.1508	0.1248
2.8	0.1391	0.1698	0.1386	0.1019
3.0	0.1350	0.1614	0.1269	0.0828
3.2	0.1305	0.1528	0.1157	0.0670
3.4	0.1257	0.1440	0.1050	0.0539
3.6	0.1207	0.1353	0.0949	0.0433
3.8	0.1155	0.1268	0.0853	0.0345
4.0	0.1103	0.1186	0.0764	0.0274
4.2	0.1051	0.1106	0.0681	0.0217
4.4	0.0999	0.1029	0.0605	0.0171
4.6	0.0948	0.0954	0.0536	0.0136
4.8	0.0898	0.0882	0.0473	0.0107
5.0	0.0849	0.0813	0.0417	0.0085
5.2	0.0802	0.0748	0.0367	0.0068
5.4	0.0756	0.0686	0.0322	0.0054
5.6	0.0712	0.0628	0.0284	0.0043
5.8	0.0670	0.0573	0.0249	0.0034
6.0	0.0629	0.0523	0.0219	0.0026
6.2	0.0591	0.0476	0.0192	0.0021
6.4	0.0554	0.0430	0.0168	0.0016
6.6	0.0519	0.0391	0.0137	0.0012
6.8	0.0485	0.0355	0.0115	0.0010
7.0	0.0454	0.0322	0.0101	0.0007
7.2	0.0424	0.0292	0.0088	0.0006
7.4	0.0396	0.0265	0.0076	0.0004
7.6	0.0370	0.0240	0.0067	0.0003
7.8	0.0345	0.0217	0.0058	0.0002
8.0	0.0321	0.0197	0.0050	0.0002
8.2	0.0299	0.0178	0.0044	0.0001
8.4	0.0278	0.0161	0.0038	0.0001
8.6	0.0259	0.0145	0.0033	
8.8	0.0241	0.0131	0.0029	
9.0	0.0224	0.0118	0.0025	
9.2	0.0208	0.0107	0.0022	
9.4	0.0193	0.0096	0.0019	
9.6	0.0179	0.0087	0.0016	
9.8	0.0166	0.0078	0.0014	
10.0	0.0154	0.0070	0.0012	



Table 2.

$E_n$ MeV	N(E')			
	Sb	I	Cs	Ce
0.2	0.3771	0.3829	0.3148	0.3405
0.4	0.4923	0.4987	0.4251	0.4343
0.6	0.5239	0.5290	0.4663	0.4565
0.8	0.5082	0.5112	0.4654	0.4448
1.0	0.4679	0.4689	0.4404	0.4182
1.2	0.4169	0.4165	0.4031	0.3851
1.4	0.3634	0.3619	0.3607	0.3484
1.6	0.3118	0.3097	0.3177	0.3101
1.8	0.2644	0.2620	0.2765	0.2724
2.0	0.2221	0.2198	0.2384	0.2370
2.2	0.1851	0.1830	0.2041	0.2044
2.4	0.1536	0.1516	0.1737	0.1751
2.6	0.1267	0.1249	0.1471	0.1491
2.8	0.1040	0.1025	0.1240	0.1263
3.0	0.0850	0.0837	0.1041	0.1064
3.2	0.0691	0.0681	0.0870	0.0893
3.4	0.0560	0.0552	0.0725	0.0746
3.6	0.0452	0.0446	0.0602	0.0621
3.8	0.0364	0.0359	0.0499	0.0515
4.0	0.0291	0.0288	0.0412	0.0425
4.2	0.0233	0.0230	0.0339	0.0351
4.4	0.0186	0.0184	0.0279	0.0289
4.6	0.0148	0.0147	0.0230	0.0239
4.8	0.0119	0.0118	0.0190	0.0198
5.0	0.0096	0.0095	0.0158	0.0165
5.2	0.0077	0.0077	0.0132	0.0137
5.4	0.0062	0.0061	0.0109	0.0114
5.6	0.0049	0.0049	0.0090	0.0094
5.8	0.0039	0.0039	0.0074	0.0077
6.0	0.0031	0.0031	0.0061	0.0064
6.2	0.0024	0.0024	0.0050	0.0052
6.4	0.0019	0.0019	0.0041	0.0042
6.6	0.0015	0.0015	0.0033	0.0034
6.8	0.0011	0.0011	0.0027	0.0028
7.0	0.0009	0.0009	0.0021	0.0022
7.2	0.0007	0.0007	0.0017	0.0018
7.4	0.0005	0.0005	0.0014	0.0014
7.6	0.0004	0.0004	0.0011	0.0011
7.8	0.0003	0.0003	0.0009	0.0009
8.0	0.0002	0.0002	0.0007	0.0007
8.2	0.0002	0.0002	0.0005	0.0005
8.4	0.0001	0.0001	0.0004	0.0004
8.6	0.0001	0.0001	0.0003	0.0003
8.8			0.0002	0.0002
9.0			0.0002	0.0002
9.2			0.0001	0.0002
9.4			0.0001	0.0001



Table 3

E <sub>n</sub> MeV	N(E)			
	Ta	Hg	Cr	Mn
0.2	0.4173	0.3511	0.2733	0.1790
0.4	0.5482	0.4468	0.3544	0.2521
0.6	0.5777	0.4854	0.3829	0.2976
0.8	0.5511	0.4803	0.3765	0.3219
1.0	0.4968	0.4504	0.3491	0.3301
1.2	0.4319	0.4091	0.3124	0.3263
1.4	0.3662	0.3633	0.2724	0.3141
1.6	0.3051	0.3182	0.2347	0.2959
1.8	0.2509	0.2754	0.2042	0.2739
2.0	0.2044	0.2362	0.1866	0.2499
2.2	0.1654	0.2006	0.1782	0.2252
2.4	0.1331	0.1685	0.1687	0.2007
2.6	0.1067	0.1398	0.1586	0.1773
2.8	0.0853	0.1152	0.1480	0.1555
3.0	0.0681	0.0943	0.1374	0.1359
3.2	0.0542	0.0770	0.1268	0.1188
3.4	0.0431	0.0629	0.1165	0.1044
3.6	0.0341	0.0512	0.1065	0.0929
3.8	0.0270	0.0417	0.0971	0.0846
4.0	0.0213	0.0338	0.0881	0.0786
4.2	0.0168	0.0274	0.0797	0.0728
4.4	0.0131	0.0222	0.0718	0.0672
4.6	0.0103	0.0179	0.0645	0.0619
4.8	0.0080	0.0144	0.0578	0.0568
5.0	0.0062	0.0116	0.0516	0.0520
5.2	0.0048	0.0093	0.0459	0.0474
5.4	0.0037	0.0074	0.0408	0.0432
5.6	0.0029	0.0059	0.0361	0.0392
5.8	0.0022	0.0047	0.0319	0.0355
6.0	0.0017	0.0038	0.0239	0.0321
6.2	0.0013	0.0030	0.0219	0.0289
6.4	0.0010	0.0024	0.0192	0.0260
6.6	0.0007	0.0019	0.0169	0.0233
6.8	0.0005	0.0015	0.0149	0.0209
7.0	0.0004	0.0012	0.0130	0.0186
7.2	0.0003	0.0009	0.0114	0.0166
7.4	0.0002	0.0007	0.0100	0.0147
7.6	0.0002	0.0005	0.0088	0.0131
7.8	0.0001	0.0004	0.0077	0.0116
8.0		0.0003	0.0067	0.0102
8.2		0.0003	0.0058	0.0091
8.4		0.0002	0.0051	0.0080
8.6		0.0001	0.0045	0.0071
8.8		0.0001	0.0039	0.0063
9.0			0.0034	0.0055
9.2			0.0030	0.0049
9.4			0.0026	0.0043
9.6			0.0022	0.0038
9.8			0.0019	0.0033
10.0			0.0017	0.0029



Table 4.

E <sub>n</sub> MeV	N(E)			
	Zn	Sr	Pb	Bi
0.2	0.2714	0.2663	0.1954	0.1941
0.4	0.3659	0.3643	0.2871	0.2877
0.6	0.4089	0.4097	0.3374	0.3405
0.8	0.4159	0.4192	0.3584	0.3642
1.0	0.3988	0.4052	0.3594	0.3677
1.2	0.3670	0.3767	0.3474	0.3576
1.4	0.3276	0.3402	0.3275	0.3389
1.6	0.2862	0.3005	0.3031	0.3150
1.8	0.2467	0.2608	0.2770	0.2887
2.0	0.2124	0.2235	0.2507	0.2615
2.2	0.1864	0.1901	0.2255	0.2349
2.4	0.1658	0.1617	0.2021	0.2094
2.6	0.1467	0.1389	0.1810	0.1857
2.8	0.1298	0.1213	0.1619	0.1639
3.0	0.1156	0.1093	0.1443	0.1441
3.2	0.1034	0.0992	0.1282	0.1263
3.4	0.0922	0.0895	0.1136	0.1105
3.6	0.0821	0.0804	0.1004	0.0963
3.8	0.0730	0.0720	0.0885	0.0838
4.0	0.0651	0.0641	0.0778	0.0728
4.2	0.0577	0.0569	0.0683	0.0631
4.4	0.0510	0.0504	0.0598	0.0545
4.6	0.0449	0.0444	0.0523	0.0470
4.8	0.0394	0.0390	0.0456	0.0405
5.0	0.0344	0.0342	0.0397	0.0348
5.2	0.0300	0.0299	0.0345	0.0299
5.4	0.0260	0.0260	0.0299	0.0256
5.6	0.0225	0.0226	0.0259	0.0219
5.8	0.0194	0.0196	0.0225	0.0187
6.0	0.0167	0.0169	0.0195	0.0159
6.2	0.0143	0.0145	0.0169	0.0136
6.4	0.0122	0.0125	0.0146	0.0116
6.6	0.0104	0.0107	0.0127	0.0100
6.8	0.0135	0.0091	0.0110	0.0086
7.0	0.0114	0.0077	0.0095	0.0073
7.2	0.0097	0.0065	0.0082	0.0062
7.4	0.0082	0.0055	0.0071	0.0053
7.6	0.0069	0.0046	0.0061	0.0045
7.8	0.0058	0.0092	0.0053	0.0038
8.0	0.0049	0.0077	0.0045	0.0032
8.2	0.0041	0.0065	0.0039	0.0027
8.4	0.0035	0.0054	0.0033	0.0023
8.6	0.0029	0.0046	0.0028	0.0019
8.8	0.0025	0.0038	0.0024	0.0016
9.0	0.0021	0.0032	0.0020	0.0013
9.2	0.0017	0.0027	0.0017	0.0011
9.4	0.0015	0.0022	0.0014	0.0009
9.6	0.0012	0.0019	0.0015	0.0007
9.8	0.0010	0.0016	0.0013	0.0006
10.0	0.0008	0.0013	0.0010	0.0005



Table 5

$E_n$ MeV	N(E)				
	$Mg_{nat.}$	$^{25}Mg$	$S_{nat.}^{def.}$	$S_{nat.}^{non.def.}$	$^{34}S_{non.def.}$
0.2	0.0979	0.1339	0.0658	0.0805	0.2130
0.4	0.1365	0.1886	0.0958	0.1161	0.2847
0.6	0.1652	0.2306	0.1195	0.1436	0.3240
0.8	0.1857	0.2617	0.1381	0.1644	0.3381
1.0	0.1993	0.2836	0.1520	0.1793	0.3335
1.2	0.2075	0.2977	0.1622	0.1895	0.3157
1.4	0.2112	0.3054	0.1691	0.1956	0.2892
1.6	0.2113	0.3077	0.1733	0.1985	0.2578
1.8	0.2087	0.3055	0.1752	0.1986	0.2251
2.0	0.2041	0.2998	0.1754	0.1967	0.1936
2.2	0.1980	0.2913	0.1741	0.1931	0.1659
2.4	0.1909	0.2805	0.1718	0.1883	0.1437
2.6	0.1833	0.2680	0.1686	0.1827	0.1301
2.8	0.1755	0.2542	0.1649	0.1764	0.1239
3.0	0.1680	0.2396	0.1604	0.1694	0.1174
3.2	0.1502	0.1224	0.1553	0.1619	0.1106
3.4	0.1430	0.1121	0.1497	0.1541	0.1037
3.6	0.1356	0.1019	0.1437	0.1460	0.0968
3.8	0.1283	0.0920	0.1381	0.1384	0.1014
4.0	0.1210	0.0824	0.1318	0.1304	0.0941
4.2	0.1138	0.0733	0.1256	0.1226	0.0871
4.4	0.1069	0.0647	0.1193	0.1150	0.0805
4.6	0.1001	0.0567	0.1132	0.1076	0.0742
4.8	0.0936	0.0492	0.1072	0.1006	0.0683
5.0	0.0874	0.0423	0.1014	0.0938	0.0628
5.2	0.0815	0.0361	0.0957	0.0874	0.0576
5.4	0.0758	0.0305	0.0902	0.0813	0.0528
5.6	0.0705	0.0255	0.0849	0.0755	0.0483
5.8	0.0655	0.0212	0.0799	0.0701	0.0441
6.0	0.0608	0.0176	0.0750	0.0650	0.0403
6.2	0.0564	0.0146	0.0704	0.0602	0.0367
6.4	0.0523	0.0122	0.0660	0.0556	0.0335
6.6	0.0485	0.0105	0.0618	0.0514	0.0305
6.8	0.0450	0.0096	0.0579	0.0475	0.0277
7.0	0.0417	0.0089	0.0541	0.0438	0.0252
7.2	0.0386	0.0082	0.0505	0.0404	0.0229
7.4	0.0358	0.0076	0.0472	0.0372	0.0207
7.6	0.0331	0.0070	0.0440	0.0342	0.0188
7.8	0.0306	0.0064	0.0411	0.0315	0.0170
8.0	0.0283	0.0060	0.0383	0.0290	0.0154
8.2	0.0261	0.0054	0.0356	0.0266	0.0139
8.4	0.0241	0.0050	0.0332	0.0244	0.0126
8.6	0.0222	0.0046	0.0308	0.0224	0.0114
8.8	0.0205	0.0042	0.0287	0.0206	0.0103
9.0	0.0189	0.0039	0.0266	0.0189	0.0093
9.2	0.0174	0.0036	0.0247	0.0173	0.0084
9.4	0.0160	0.0033	0.0230	0.0158	0.0076
9.6	0.0147	0.0030	0.0213	0.0145	0.0068
9.8	0.0135	0.0027	0.0198	0.0133	0.0061
10.0	0.0124	0.0025	0.0183	0.0121	0.0055



Table 6

E <sub>n</sub> MeV	N(E)	
	Ca <sub>nat.</sub>	<sup>44</sup> Ca
0.2	0.1083	0.2666
0.4	0.1562	0.3583
0.6	0.1916	0.4061
0.8	0.2164	0.4216
1.0	0.2327	0.4139
1.2	0.2420	0.3904
1.4	0.2456	0.3568
1.6	0.2448	0.3178
1.8	0.2404	0.2769
2.0	0.2333	0.2368
2.2	0.2243	0.1998
2.4	0.2138	0.1674
2.6	0.2024	0.1408
2.8	0.1905	0.1210
3.0	0.1783	0.1098
3.2	0.1660	0.1002
3.4	0.1539	0.0910
3.6	0.1419	0.0822
3.8	0.1304	0.0740
4.0	0.1193	0.0663
4.2	0.1089	0.0591
4.4	0.0992	0.0525
4.6	0.0901	0.0465
4.8	0.0818	0.0410
5.0	0.0738	0.0217
5.2	0.0667	0.0191
5.4	0.0603	0.0167
5.6	0.0544	0.0147
5.8	0.0490	0.0128
6.0	0.0441	0.0112
6.2	0.0397	0.0098
6.4	0.0356	0.0085
6.6	0.0320	0.0074
6.8	0.0287	0.0065
7.0	0.0257	0.0056
7.2	0.0230	0.0049
7.4	0.0205	0.0042
7.6	0.0184	0.0037
7.8	0.0164	0.0032
8.0	0.0146	0.0028
8.2	0.0130	0.0024
8.4	0.0116	0.0021
8.6	0.0104	0.0018
8.8	0.0092	0.0015
9.0	0.0082	0.0013
9.2	0.0073	0.0011
9.4	0.0065	0.0010
9.6	0.0058	0.0009
9.8	0.0051	0.0007
10.0	0.0046	0.0006



# FIGURE CAPTIONS

- Fig. 1      Logarithmic plot of  $N(E)/E$  for neutron emissions following bombardment Na, Mg, S, K, Ca and Ti with 14 MeV neutrons. The experimental values from refs. [3,4] indicated by •. The solid curves give the calculated values for targets of natural isotopic abundance, while the dashed lines show those only for targets without components not giving (n,2n) reactions.
- Fig. 2      Logarithmic plot of  $N(E)/E^{5/11}$  for neutron emissions following bombardment In, Sb, I, Cs, Ce, Ta and Hg with 14 MeV neutrons. The experimental values from ref. [4] indicated by •. The solid curves give the calculated values for targets of natural isotopic abundance.
- Fig. 3      Logarithmic plot of  $N(E)/E$  for neutron emission following bombardment Cr, Mn, Zn, Sr, Pb and Bi with 14 MeV neutrons. The experimental values from ref. [3,4] indicated by •. The solid curves give the calculated values for targets of natural isotopic abundance.



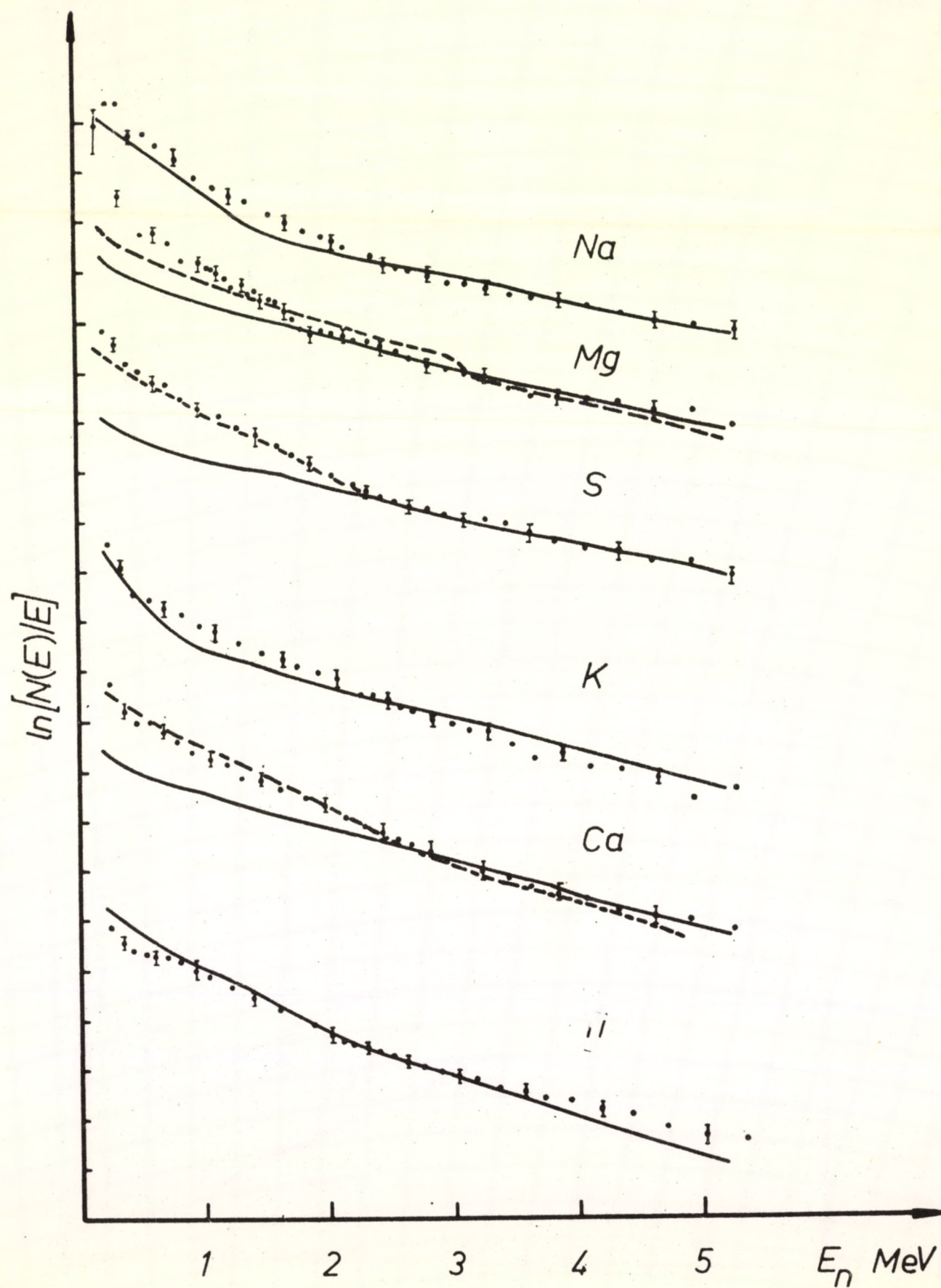


Fig. 1



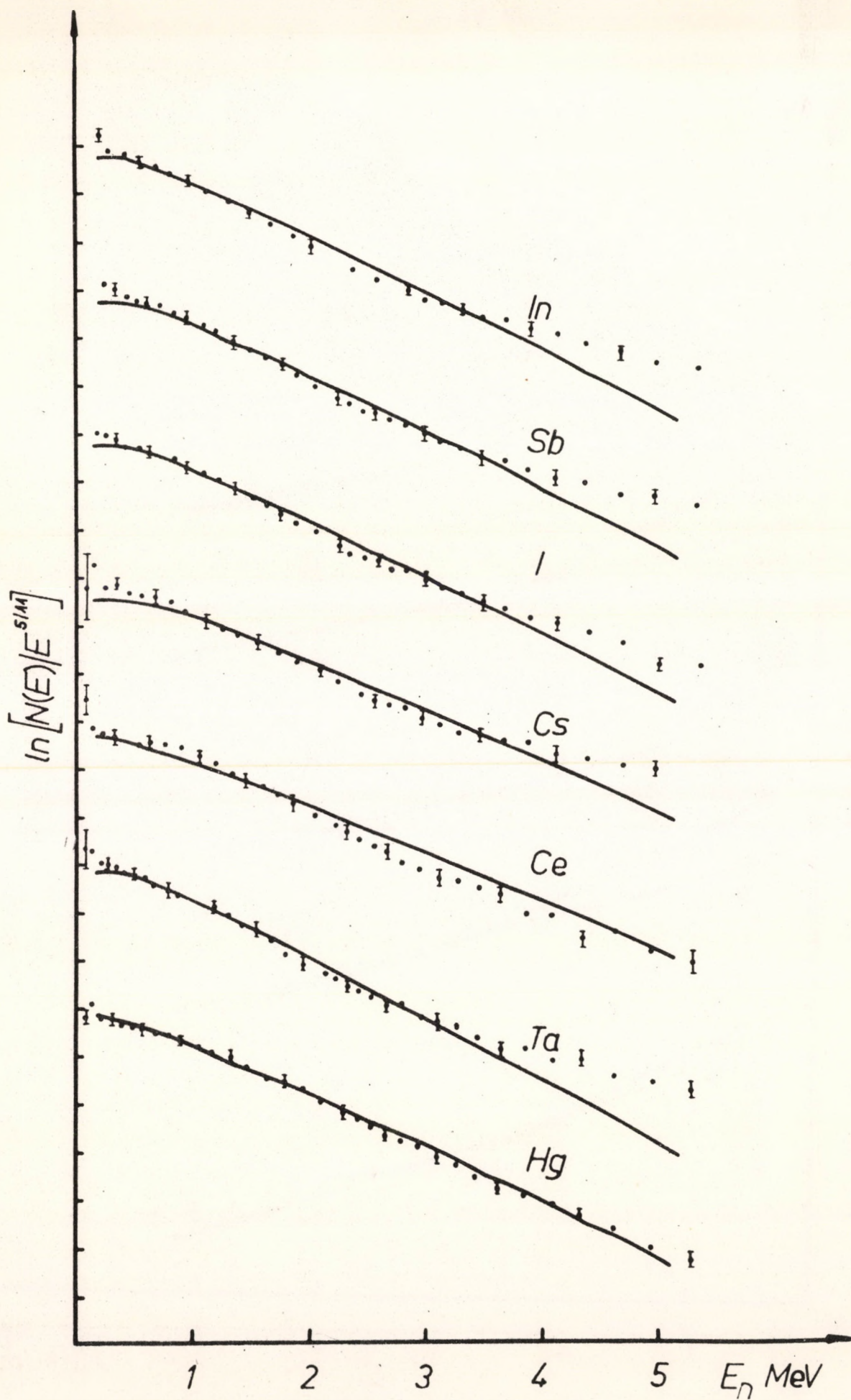


Fig. 2.



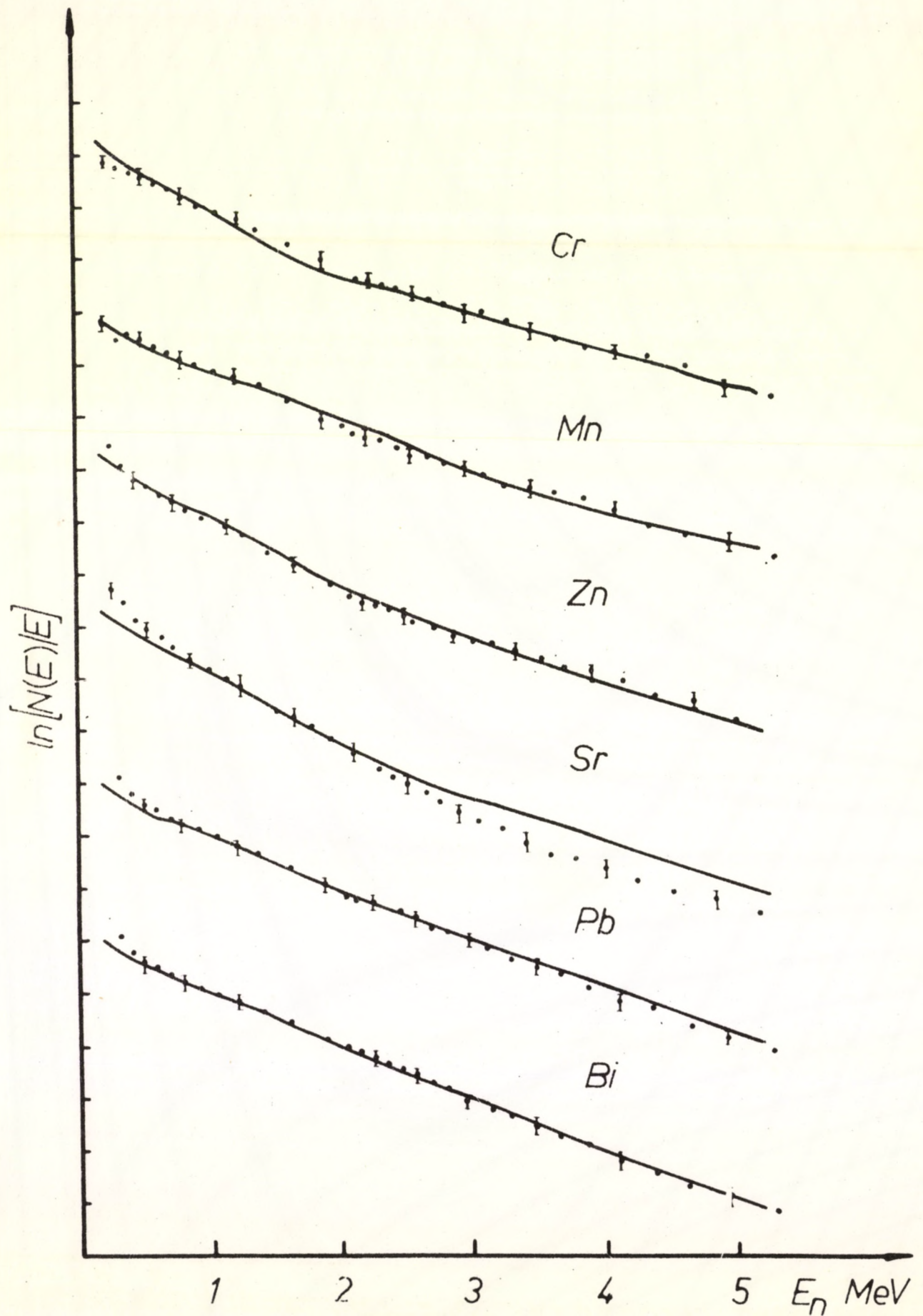


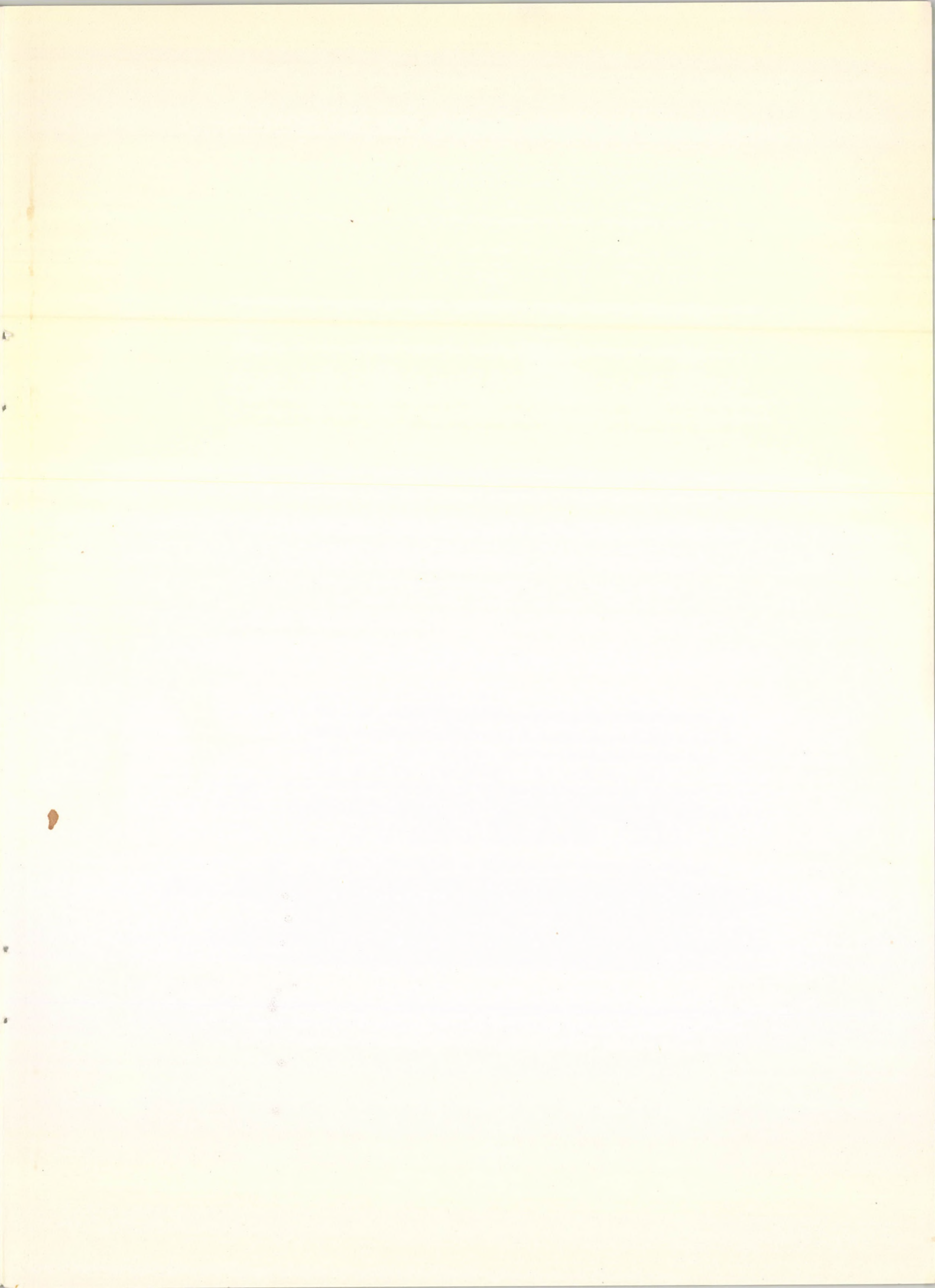
Fig. 3



## REFERENCES

- [1] F.M.Blatt and V.F.Weisskopf: Theoretical Nuclear Physics, J.Wiley et Sons Inc., New-York, (1952)
- [2] K.J.LeCouteur and D.W.Lang, Nucl.Phys. 13 (1959) 32
- [3] V.B.Anufrienko, B.V.Devkin, G.V.Kotelnikova, Yu.S.Kulabuhov, G.N.Lovchikova, O.A.Salnikov, L.A.Timokhin, V.Trubnikov and N.I.Fetisov, Jadernaya Fizika 2 (1965) 826
- [4] O.A.Salnikov, N.I.Fetisov, G.N.Lovchikova, G.V.Kotelnikova, V.B.Anufrienko and B.V.Devkin, Jadernaya Fizika 6 (1966) 1154
- [5] I.Dostrovsky, Z.Fraenkel and G.Friedlander, Phys.Rev. 116 (1959) 683
- [6] A.Gilbert and A.G.W.Cameron, Can.J.Phys. 43 (1965) 1446
- [7] W.Hauser and H.Feshbach, Phys.Rev. 87 (1952) 366
- [8] Gy.Kluge, Phys.Letters 37B (1971) 217

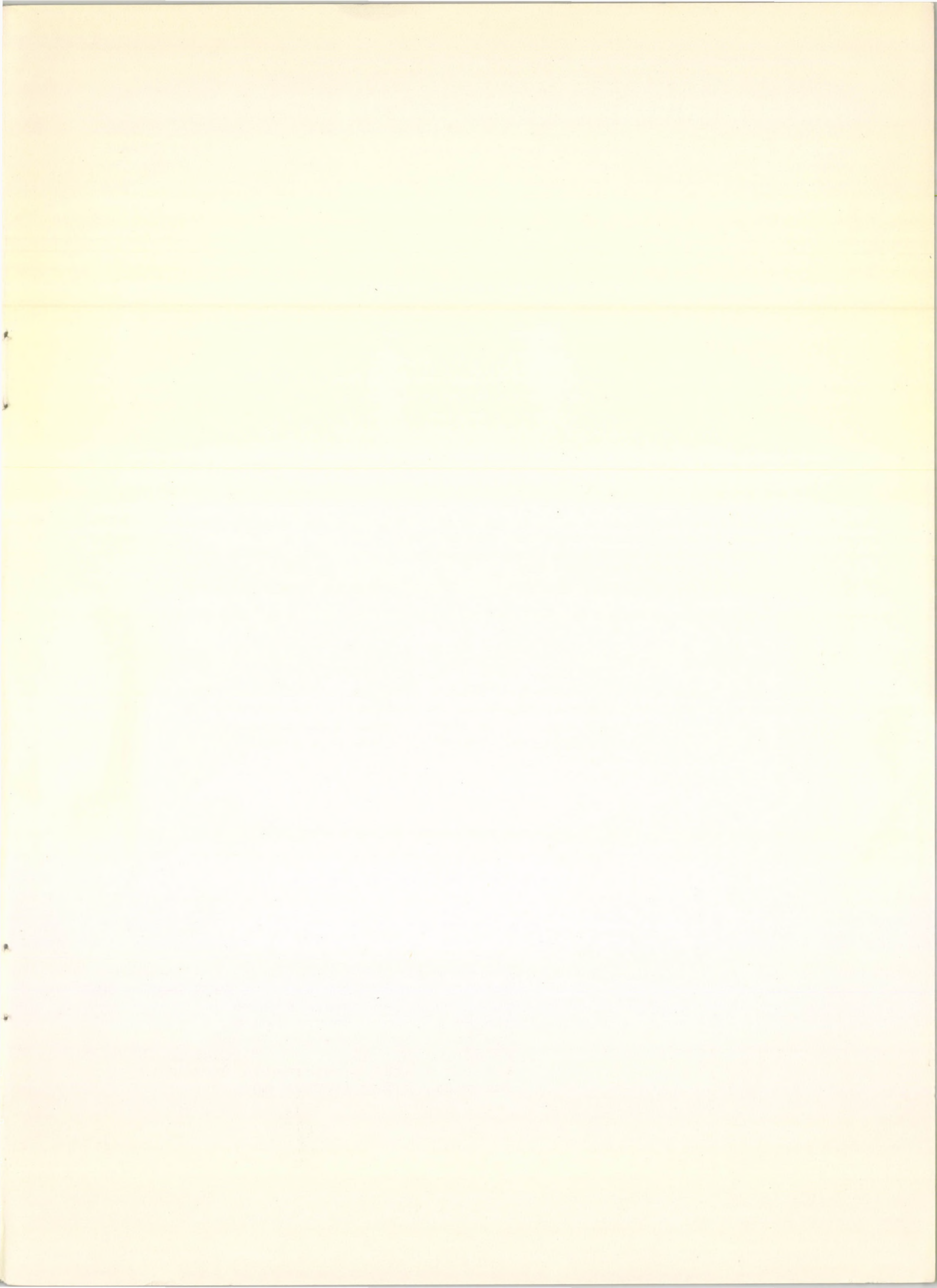
















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